Decompression Sickness (DCS) Risk Mitigation V1 4.4.3.6.1; V2 6002, 6008, 6009, 11032 Overview

Overview

Decompression Sickness Mitigation/Prevention

Executive Summary

Denitrogenation protocols (removing the nitrogen from the body) shall be employed to minimize the formulation of gas emboli (bubbles) forming during an EVA. Taking the body from a higher pressure to a lower pressure too quickly and without adequate denitrogenation can cause bubbles to form. DCS also needs to be minimized during off-nominal events such as cabin depressurization. If a suit (LEA-Launch, Entry, Abort) is implemented during a cabin depressurization, then it needs to be at sufficient pressure relative to the initial cabin pressure to be effective. DCS mitigation protocols are implemented through the combination of habitat and EVA suit pressure and breathing gas procedures to achieve nominal mission operations.

Requirements/Standards Overview:

NASA-STD-3001 Volume 1

4.4.3.6.1 Decompression Sickness (DCS) Prevention

Nominal planned EVAs shall be performed using validated protocols that allow crewmembers to perform each EVA with a total risk of DCS ≤ 15percent per person with 95 percent statistical confidence.

Validated protocols shall meet the following historical criteria for acceptance based on ground studies:

a. DCS ≤ 15percent (includes Type I and cutis marmorata).

b. Grade IV VGE ≤20percent.

c. No Type II DCS.

NASA-STD-3001 Volume 2

[V2 6002] Inert Diluent Gas

For mission durations in excess of 2 weeks, the atmosphere shall contain a physiologically inert diluent gas to prevent lung collapse.

[V2 6008] Decompression Sickness (DCS) Risk Identification

Each program shall define mission-unique DCS mitigation strategies to achieve the level of acceptable risk of DCS as defined in NASA-STD-3001, Volume 1, section 4.4.3.6.1, Decompression Sickness Prevention.

[V2 6009] Decompression Sickness Treatment Capability

The system shall provide a DCS treatment capability.

[V2 11032] LEA Suited Decompression Sickness Prevention Capability

LEA spacesuits shall be capable of a minimum of 40 kPa (5.8 psia) operating pressure to protect against Type II decompression sickness in the event of a cabin depressurization.

Background

Decompression Sickness Mitigation/Prevention/Treatment

- DCS is a major concern in spaceflight, as well as terrestrially. It is of high importance due to the consequences during and after it occurs.
- DCS is the result of nitrogen bubbles (or other gas emboli) causing damage to tissue.
  - Gas emboli can be classified as venous gas emboli (VGE) or arterial gas emboli (AGE).
  - VGE are removed from the circulation by the lungs, where as AGE are more serious since they compromise tissue oxygenation.
- Conkin, et al (3) describes DCS as, "[When an] astronaut travels to a hypobaric environment, the amount of inert gas in excess of what can be held in solution at the new lower pressure has the potential to come out of solution to form gas spaces that can displace or otherwise damage tissues."
- DCS is typically mitigated with prebreathe protocols – denitrogenation of the body with oxygen.
- The risk of DCS is shown to increase during ambulation and periods of increased lower body activity on Earth
- DCS risk is significantly increased by ambulation and physical activity during altitude exposure meaning that ISS microgravity prebreathe protocols are not applicable to planetary EVA
- Apollo used a 100% O2 cabin environment which eliminated DCS risk during EVA

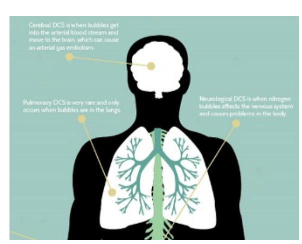
Risks of Decompression Sickness

Types of DCS:

- **Type I:** joint pain, single extremity tingling or numbness, and mild skin symptoms

Type I: Joint Pain

- **Type II:** central nervous system or cardiovascular symptoms (potentially fatal). Symptoms range from muscle weakness, confusion, impaired balance to stroke.



Type II: Gas bubbles in pulmonary/lungs (chokes), cerebral/brain, neurological

The goal is to limit DCS risk to within acceptable levels through validated prebreathe protocols.

Reference Data

Decompression Sickness Mitigation/Prevention/Treatment

Past NASA Decompression Protocols for prevention of DCS

NASA has never experienced a Type II event in spaceflight

In-suit 4-hour Prebreathe

Astronaut breathes 100% O2 in the spacesuit at 14.7 psia for 4 hours.

Campout Protocol

Significantly reduces the required in-suit prebreathe duration by having EVA crewmembers “camp out” in the ISS airlock at 10.2 psia, 26.5% O2 during the night prior to their EVA. For various operational reasons, the time at 10.2 psia is limited to 8 hours and 40 minutes.

Exercise Protocol

Intense, short exercise regimen at 14.7 psia while breathing 100% O2 combined with in-suit prebreathe at 10.2 psia.

In-Suit Light Exercise (ISLE) Protocol

A longer period of mild exercise in the EMU. The ISLE protocol shares many steps with the exercise prebreathe protocol but differs in that 40 minutes are spent breathing 100% O2 by mask followed by a 20-minute depressurization to 10.2 psia.

Notes:

- DCS risk is significantly increased by ambulation and physical activity during altitude exposure meaning that ISS microgravity prebreathe protocols are not applicable to planetary EVA
- Apollo used a 100% O2 cabin environment which eliminated DCS risk during EVA

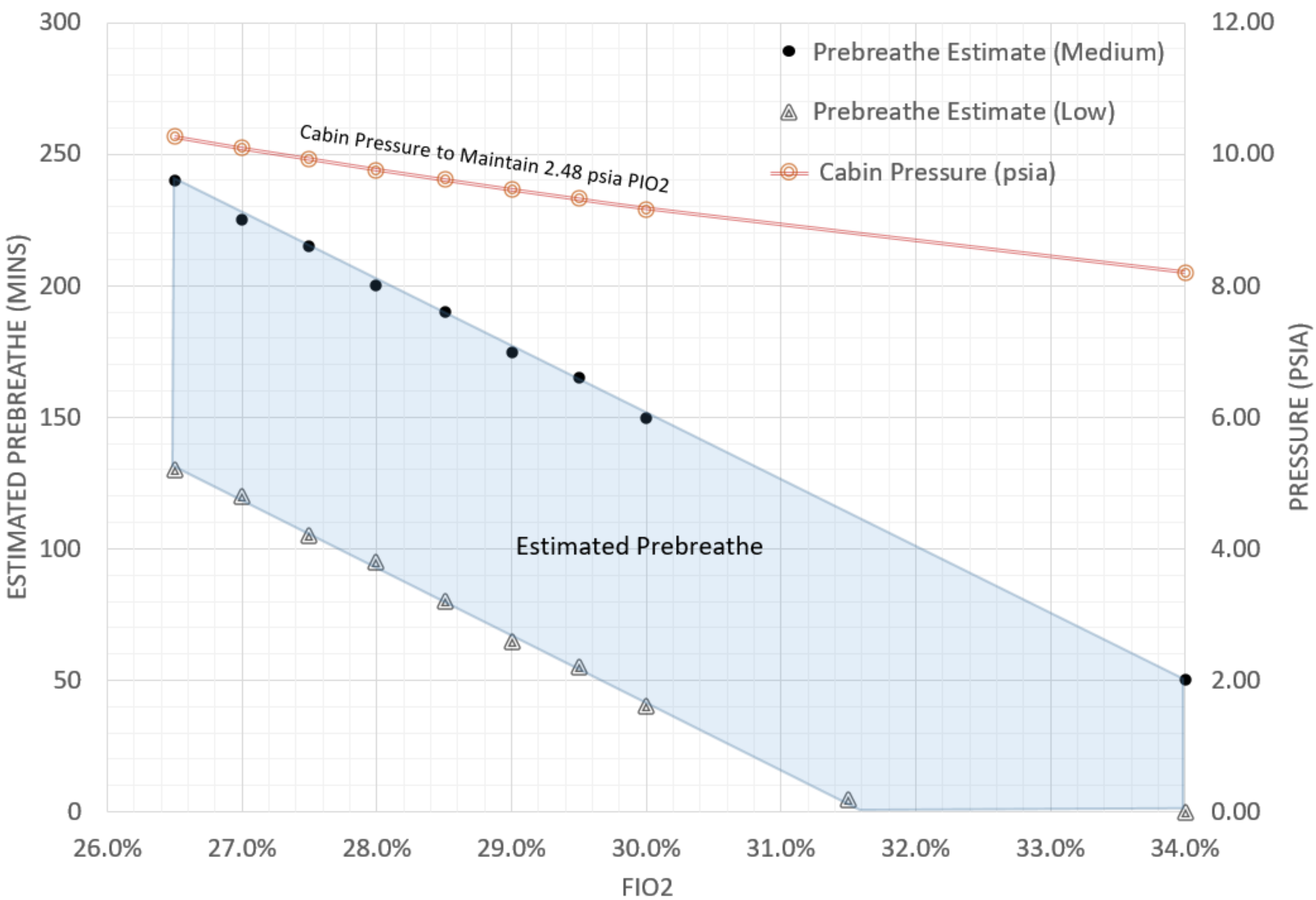
Past prebreathe protocols are between 3-5 hours. Utilizing a lower cabin pressure/higher oxygen concentration like 8.2 psia with 34% O2 can minimize the time to denitrogenate the body which saves time and consumables.

See next page for a comparison of prebreathe durations compared to atmosphere compositions.

Reference Data

Decompression Sickness Mitigation/Prevention/Treatment

Approximate prebreathe durations for different atmosphere compositions



Application Notes

Decompression Sickness Mitigation/Prevention/Treatment

Design Guidance

- The key to preventing DCS is to denitrogenate the body by breathing higher levels of oxygen and optimizing the pressures of the cabin and the suit.
- DCS requires cross discipline activities to provide effective mitigation:
  - Habitat pressure and oxygen concentration
  - Suit Pressure and oxygen concentration
- Duration of prebreathe is determined by the pressure, percent oxygen and nitrogen of the atmosphere.
- Ineffective designs can consume larger amounts of oxygen and take more time prior to initiating an EVA (from many hours to minutes).
- Treatment is performed using the total pressures from the vehicle and suit atmospheres.
  - When DCS symptoms occur, the 8.2 psia suit and 8.2 psia cabin are combined to resolve symptoms (16.4 psia total in the recommended scenario below)
  - If symptoms persist, the cabin pressure is further increased
- Type II DCS prevention during a cabin depressurization may require the use of a suit (e.g. LEA suit)
  - The suit should be able to reach sufficient pressure to lessen DCS symptoms, if they cannot be prevented altogether
  - An LEA suit pressure of 5.8 psia has been shown to reduce the risk of Type II DCS to <15% for a rapid depressurization; for more information, reference the Decompression Events and LEA Suits Technical Brief

Example Prebreathe Table

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Gateway Atmosphere *	14.7, 21% O2	10.2 psi, 26.5% O2	10.2 psi, 26.5% O2	14.7 psi, 21% O2	14.7 psi, 21% O2
Lander *** Atmosphere	10.2 psi, 26.5%	10.2 psi, 26.5%	8.2 psi, 34%	14.7 psi, 21% O2	8.2 psi, 34%
Prebreathe prior to and/or during descent?	1+ hours TBR (on mask, or in-suit)	None required	None required	None	3+ hours TBR (on mask, or in-suit)
Minimum time in Lander prior to EVA	Longer prebreathe if EVA prior to 36 hours	No constraint	No constraint after 24 hours Small PB penalty if earlier than 24hrs	None	Longer prebreathe if EVA prior to 36 hours
Estimated O2 prebreathe prior to EVA **	Estimate 3-3.5 hours TBR	Estimate 3-3.5 hours TBR	Estimate 0 -30 mins TBR	Estimate 5-6 hours TBR	Estimate 0 -30 mins TBR

* Assume 36+ hours at atmosphere prior to lander undocking; balance N2 in all atmospheres
** Estimated prebreathe times are approximations and not validated; assume 6 hour EVA @ 4.3 psia
*** The Conops of this mission requires the use of a reduced pressure, O2 enriched environment to provide staged denitrogenation. Scenario 4 is provided for reference, but would not facilitate these assumed Conops

Assumed Conops***	
Orion transit to Gateway	TBD days
Orion docked to Gateway	5 days
Lander undock, transit to lunar surface (12 hrs)	Lunar Day 1
Post landing safe-ing & reconfig (~4 hrs)	
Crew Sleep (8 hrs)	
EVA 1	Lunar Day 2
EVA 2	Lunar Day 3
No EVA	Lunar Day 4
EVA 3	Lunar Day 5
EVA 4	Lunar Day 6
Lander ascent, return to Gateway	Lunar Day 7

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Revision Updates

Slide 1
- Minor update to Executive Summary

Slide 2
- Updated Background information

Slide 3
- Past Protocols updates with additional information
- Additional notes added
- Table and references removed and updated on additional slides
- Application Notes slide removed completely

Slide 4
- New slide to capture new pre-breathe table

Slide 6
- Added slide with additional references